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Drainage of Farm Lands.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., December 21, 1903.

Sir: I have the honor to transmit herewith copy of an article on Drainage of Farm Lands, prepared by C. G. Elliott, drainage expert of this Office. There is a large and growing demand for information as to the best methods of draining wet lands and the cost of such drainage. This bulletin is prepared in response to that demand, and its publication as a farmers' bulletin is recommended. It is designed to take the place of Farmers' Bulletin No. 40, Farm Drainage, which was first issued in March, 1896.

Respectfully,
A. C. True,
Director.

Hon. James Wilson,
Secretary.

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DRAINAGE OF FARM LANDS.

INTRODUCTION.

"In the cultivation of retentive soils," says Waring, "drainage is the key of all improvement."

Farmers frequently desire an improvement in methods and in the general management of their lands without being sufficiently informed regarding the specific changes that will be necessary to bring it about or clear in their minds as to the profits that would accrue should such changes be made. When a farmer finds his land too wet for cultivation, he admits the necessity of drainage for the time being, but often hopes that the following season may be more favorable—which hope is frequently realized—and so takes the loss as one of the contingencies of the industry. He waits in the spring for slow natural drainage and evaporation to relieve his land of the surplus water and permit the sun to dry and warm the soil sufficiently for the reception and germination of the seed, when by the aid of drainage the seeding could be done a week or ten days earlier. The injury resulting to crops growing upon land imperfectly drained when the season is not the most favorable is frequently taken as unavoidable—one of the vicissitudes of farming rather than a loss to be prevented by the use of well located and constructed drains.

Facts which are easily discerned by the casual observer have pressed the subject of drainage home to both practical farmers and nonresident landowners in a most emphatic way. Those who have gone further into the subject of soil improvement by drainage have discovered greater advantages and more surprising benefits than were formerly thought possible. It is conceded to be a necessary accompaniment of scientific agriculture, and our most progressive farmers have taken advantage of it to a greater extent than is generally supposed. It is an improvement applicable to all land not possessing natural drainage, and hence is required for the attainment of the best results from some of our most fertile land. The farmer, when convinced that it will be to his interest to construct some kind of a drainage system for the improvement of his soil, desires to know how to plan and perform the work in an effective way at an expense not exceeding the limit of profitable returns which can reasonably be expected. He will find it an advantage to have an intelligent idea of

the theory as well as of the practice of drainage in order that he may adapt his work to the several varieties of soil and conditions with which he has to deal.

NATURE OF A DRAINED SOIL.

A drained soil is one which is moist but not saturated with water. Soils used for the production of the plants most prized by the farmer, gardener, or fruit grower must, in addition to other necessary elements, contain a certain percentage of water in order to yield the largest possible returns. This is usually termed "moisture," and soils in which the proper percentage of moisture exists are commonly called "dry soils," to distinguish them from those containing a surplus of water, which are called "wet soils." The farmer, therefore, in speaking of a "dry" soil does not mean one which is devoid of water, but one which does not contain enough water to hinder or prevent the growth of his plants, while the term "wet" indicates one that contains more water than is needed, the presence of which prevents the plants from reaching their greatest perfection. A perfectly dry soil is dead, and is worthless for producing crops. A soil which is completely saturated with water will produce nothing but aquatic plants and hence is worthless for cereals and other valuable products.

Plants take their nutriment from the soil in liquid form only, it having been prepared by the action of heat and moisture on the elements present. An excess of moisture reduces the temperature, excludes the air, and dilutes the plant food, thus retarding or entirely stopping the growth of the plant as effectually as a lack of moisture.

THE MECHANICAL MAKE-UP OF SOILS.

Soil is made up of exceedingly fine particles of irregular shapes, varying composition, and different properties. It is formed by the breaking down of rocks of different composition which are disintegrated by the weather, ground up and distributed by glacial action and floods, and mixed with the products of successive ages of vegetable growth. These particles as they appear under the microscope are rough and irregular, some of them being exceedingly small. The differences in size of the particles of ordinary soils (exclusive of gravel, pebbles, etc.) are illustrated in the following classification usually adopted in the mechanical analysis of soils:

Comparative diameters of soil particles in different soils.

	Inch.
Coarse sand	0.04 to 0.02
Medium sand	.02 to .01
Fine sand	.01 to .004
Very fine sand	.004 to .002
Silt	.002 to .0002
Clay	.0002 and less.

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The peculiar shapes of soil particles as they appear under the microscope are shown in figures 1 and 2. Here it is shown that the particles of sand are not less than 200 times larger than the particles of clay.

As the soil particles can not lie together so as to form a solid mass, there is a large amount of intervening space, which in an average soil equals nearly half its volume. The smaller the particles the greater the proportion of space. Thus clay contains 65 per cent of space, while a sandy truck soil contains 37 per cent, ordinary soils varying all the way between these extremes.

FIG. 1.—Soil particles magnified 162 times.[a]

As a result of a force which is known as surface tension, each particle of soil holds a film of water over its entire surface and thus provides a supply of this material for the roots of the plant. When the quantity of water in the soil is so much greater than is required to supply that which is held by surface tension that the remaining space is filled the soil is said to be saturated. If we provide an outlet for the water the surplus will pass off by force of gravity, leaving only the films which are held by surface tension and which furnish the desired moisture to plants. Thus from 15 to 20 per cent of all the water which a soil will hold will not pass off as drainage, but will remain as capillary water to contribute to the growth of plants, and to aid further in the preparation of additional plant food. This necessary moisture moves through the soil independently of gravity by the force of capillary attraction or surface tension—as illustrated in the rise of liquids in small tubes and between surfaces of solids which are close together—which tends to distribute and equalize moisture in the soil. Where the principal supply is above or in the surface layers, it is drawn downward; where it is below, it is drawn upward.

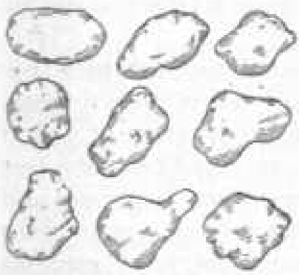

FIG 2.—Silt particles from subsoil magnified 225 times.[a]

As before stated, about 50 per cent of the volume of ordinary soils is space which is always filled with water or air. The individual spaces are larger or smaller according as the soil grains are more or less minute. A close clay soil and a very coarse sandy soil will illustrate the extremes of difference. The fine grains present more surface in a given volume of soil and hence will retain the greater quantity of moisture. The

[a] From Bulletin 65, Minnesota Experiment Station.

coarser soils will permit a much freer percolation of water and hence quicker drainage than the finer ones, since the closeness of the particles offers an additional resistance to the passage of water by gravity through the soil.

Another mechanical condition of soils has more to do with their drainage properties than the differences already noted. It is the massing of particles of different character to form compound soil grains which lie contiguous and have spaces between them. Those who have examined the physical structure of soils minutely will have observed the granular structure of soils containing a mixture of humus and clay. Some subsoils are commonly known as "joint clays" from the fact that they show natural cleavage or fractures which mark them as soils easily drained. Others of a marly, sandy, or gravelly nature mass their particles into irregular forms which can not lie close together, and are known as light subsoils. Still other clays appear to be wanting in the characteristics named, their individual particles lying com-

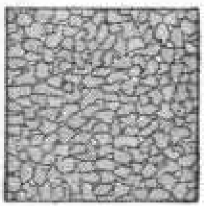

FIG. 3.—Soil grains and spaces.

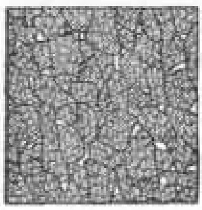

FIG. 4.—Soil particles in masses.

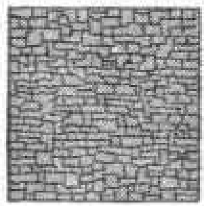

FIG. 5.—Joint clay structure.

pactly together and forming a dense mass capable of retaining a larger percentage of water than any other variety, and are commonly known as retentive or impervious soils. Some of these mechanical characteristics are illustrated in figures 3, 4, and 5.

The varieties of soils and the numberless combinations which their particles assume in such a way as to materially affect their drainage properties can not be described here. Indeed, the structure of a given soil can not be known until a personal examination and test have been made. The reading of soils for drainage operations requires a skill which can not be imparted without special field lessons; yet any close observer may soon acquire a fair degree of proficiency in judging soils within the limits of the area with which he is concerned.

NATURAL AND ARTIFICIAL DRAINAGE.

Some of our best soils have perfect natural drainage. They are underlaid with strata of material which give free passage to surplus water and are composed of elements which respond readily to the efforts of the cultivator. On the other hand, there are soils just as rich in natural fertility which are unproductive because under all ordinary circumstances they contain too much water. Whether the excess

of soil water is caused by rainfall direct or by seepage from lands which occupy a higher level, the surplus water must be removed before the soil will be in proper condition for plant growth.

The process of drainage, either natural or artificial, only regulates the quantity of water in the soil by providing the means by which its surplus may pass off by gravity, and in no case removes the moisture required by plants, since such moisture is retained by the particles of soil.

SURFACE DRAINAGE AND UNDERDRAINAGE.

Surface drainage, as commonly understood, is accomplished by open ditches which, in addition to receiving and removing water from the surface of land contiguous to them, may, if sufficiently deep, act as receiving drains for water which percolates through a porous substratum through which the ditches are excavated, and under such conditions facilitate underdrainage as well as carry off water from the surface. The advantages of removing water downward through the soil instead of over the surface may be briefly stated as follows:

The surface soil is retained entire instead of the finest and most fertile parts being carried off with every considerable rainfall.

Any plant food in manure or other fertilizer deposited upon the soil is carried into it with the water as it percolates downward from the surface, and so becomes thoroughly incorporated with the soil.

Rain water as it passes through the soil serves a most useful purpose by dissolving and preparing crude soil material for the nutrition of plants.

The soil, having been well prepared, is at all times during the growing season in readiness for the growth of plants, such growth not being hindered by stagnant water or saturation.

The frost goes out earlier in the spring, so that the planting season opens one or two weeks earlier than in the case of soils affected by surface drains only.

Where stiff clays are found the soil is made more porous, open, and friable, and roots penetrate more deeply than they do into surface-drained soils.

The effects of drought are diminished, as has been found by experience, owing to the enlarged and deepened soil bed and to the more favorable condition of the surface for preventing excessive evaporation of moisture.

It aids in making new soil out of the unprepared elements, since it permits a freer entrance of air and atmospheric heat which disintegrate soil material hitherto unavailable for use of plants.

Stubborn and refractory soils when drained are frequently so changed in texture and mechanical structure that they become easily managed and respond to cultivation with abundant crops.

OPEN DRAINS.

Underdrainage is that which directly affects the soil and puts it in proper condition for plant production. Provision for it assumes that sufficient natural water courses or artificial channels exist to carry off the water discharged by such underdrains as it may be found wise to use. It is often the case, however, that outlet channels must be provided before a system of underdrains which will operate successfully can be laid. Natural streams are often insufficient and should be improved in size and alignment. In fact, the location and water-carrying capacity of general outlets as related to the drainage area should receive particular attention in the formation of drainage plans. When it is desired to reclaim and improve large areas of level land, such tracts must be cut up into sections or districts by large open ditches in order that tile-drains may be laid in every part without necessitating the use of mains too large and costly to be profitable. While these open ditches are not desirable in themselves, since the land they occupy can not be used for any other purpose, and though they often divide the land into tracts of inconvenient shape, yet they are necessary to every system of underdrainage. They should be located with care, following the course of natural drainage as nearly as maybe, with due regard to straight courses.

When these outlet ditches are located on land belonging to one individual, he has merely to construct them as he chooses and pay the cost of the work. But in all large tracts in which a number of landowners have interests, open ditches must be constructed by the cooperation of all parties benefited. In several States methods of doing this are provided for by statute. Outlets for the drainage of tracts varying from a few hundred up to many thousand acres have been provided for in this way, each owner within the district paying a share of the expense of such work proportionate to the benefit he derives. It is intended that when these main channels have been made, each owner shall be provided with an outlet for his drainage and that all subsequent drainage of his own land shall be done at his own expense, without in any way infringing upon the rights of others, while the general outlet will be controlled by the proper officers as provided by law.

The method of improving natural channels is often suggested by the contour of the land and the conditions surrounding the tract to be drained. Such channels are usually crooked to a troublesome degree, and necessitate the division of the fields into inconvenient shapes. They are sometimes well defined by strong banks which can be changed but slightly. In other instances, where the channel winds through a tract of bottom land, it can be greatly improved by cutting off the bends and making the course as nearly straight as practicable. Because natural ditches and streams are always crooked it does not follow

that artificial drainage channels should be the same, especially where they extend through tracts where only light grades can be obtained.

Ditches upon rolling land may differ from those on level land in several important particulars. Those for the former, having a grade which gives a rapid flow, may be comparatively small and shallow. The outlets for tile-drains may, if necessary, discharge at shallow depths, since the lateral slope of the land is such that the drains may be laid at the desired depth only a short distance from their outlets. They may have narrow bottoms, since the velocity of flow is sufficient to scour and deepen them. In level land, however, it is often necessary to provide for practically the entire drainage, with but little assistance from the natural slope of the land. The depth of ditches with grades of from 1 to 4 feet per mile should ordinarily be not less than 6 feet and the bottom width not less than 4 feet. The side slopes in loam or clay soils may be made at an angle of 45°, or what is called a slope of 1 to 1. Where the soil is loose and sandy, the slope should be 2 feet horizontal to 1 foot vertical, called a slope of 2 to 1. Ditches excavated with teams and scrapers can not be profitably made with slopes less than 2 to 1.

CONSTRUCTION OF DITCHES.

The well-known method of making ditches with a plow and scoop scraper need not be described. Where the earth is sufficiently dry to afford a footing for teams and for the operation of the plow and scraper, it is an economical method of making ditches. Where the earth is dry, ditching contracts are sometimes let to farmers, who do the work when farm labor is slack, at from 7 to 10 cents per cubic yard. Ordinarily contractors will bid for such work at 10 to 14 cents under the conditions usually encountered. A large part of open-ditch work must be done when the ground is wet and in swamps under conditions where it is impossible to use teams. It is also necessary at times to make deep excavations, where water is sure to be encountered and where the earth is of such a character that it can not be handled by teams and scrapers.

There are machines which have been tried and found adapted to the work where the ordinary scraper can not be employed. For the making of small and shallow ditches what is known as the capstan ditch plow is used in some localities. It is an immense plow, which makes a ditch by cutting and throwing the earth from the center each way, its action being similar to that of a common sod plow. There are wings which push the earth thrown up 3 feet away from the edge of the ditch, leaving it in a large, continuous ridge on each side. The plow is pulled by two capstans, each of which is turned by a team of horses. The capstans are anchored ahead and their winding drums

are attached to the plow by wire ropes. This machine makes a clean-cut ditch 8 feet wide at the top, 1 foot wide at the bottom, and ordinarily limited in depth to 2½ feet. It is used on Iowa and Minnesota prairie lands where it is thought that ditches of this kind will serve the desired purpose. Contract work is taken at about 60 cents a rod for the completed ditch. In order to operate the plow the earth should be saturated with water, so that it may be cut easily and will slip from the wings readily. A section of a finished ditch is illustrated in figure 6.

In the construction of artificial channels for the purpose of reclaiming large areas of level land there is no method so satisfactory as that in which a steam dredge is used. These dredges as constructed for such purposes are of three different types. One, known as the floating dredge, begins operations at the upper end of the channel and works toward the outlet. There must be sufficient water in the ditch to float the boat which carries the engine and excavating machinery. The excavated earth is deposited on each side of the ditch at a distance of 6 to 12 feet from the edge of the channel. This style of dredge is adapted to the excavation of large channels, varying from 12 to 60 feet wide and as deep as is usually required. It has been successfully used in the Middle West for twenty years and has done more toward the reclamation of level lands than any other agency which can be named. The sides of the ditch as usually excavated have a slope of about ½ to 1, and when completed a section has approximately the form of the letter U. Where the ground is quite unstable the side slopes should be not less than 1 to 1, and the excavated earth should be left not nearer than 8 feet from the edge of the excavation.

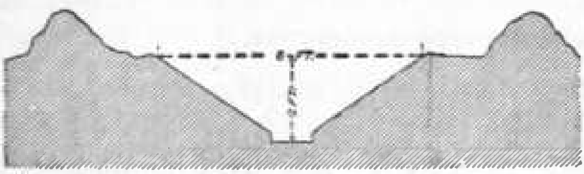

FIG. 6.—Section of capstan ditch.

Another type of steam dredge will make ditches as narrow as 4 feet at the bottom and as wide as 12 to 15 feet at the top, with side slopes of 45°, the depths ranging from 4 to 9 feet. This machine is placed at the outlet of the proposed ditch and is pulled upgrade by means of a drum which winds up a cable previously anchored ahead of the machine. No water is required in the ditch in order to operate it. It excavates to its full depth and grade and completes the work from the outlet toward the source. The machine is not used as generally as the floating dredge, not because it is less efficient, but, being adapted only to the excavation of smaller ditches where the ground is firm on both surface and bottom, it is limited in its field and hence not so much in favor with contractors.

The third steam machine which may be described has similar limitations. It is constructed to move upon the surface of the ground in advance of the excavation, instead of following up the bottom of the ditch, as does the one last described. The plant carrying the machinery rests upon long runners which slide upon movable cross blocks, and is pulled by a cable, one end of which is attached to a winding drum at the engine and the other to a log anchored some distance ahead of the machine, technically called a "dead man." The mechanism for excavation consists of two dippers which are filled by being pulled toward the machine against the earth and are dumped alternately. While one dipper is filling the other is being swung to the opposite side and emptied. This dredge, like the last mentioned, is adapted to ditches of the smaller class and to land which is sufficiently firm to support the machine upon the surface.

Dredges of the three types just described have been in successful operation for ditching purposes for twelve to twenty-five years. The boats are built and the machinery mounted upon the ground where the work is to be done. The machines cost not less than $5,000 each. They are operated by contractors, who provide themselves with full equipment and do the work by the cubic yard, under specifications and measurements made by an engineer. The work required by these machines is performed at a cost of 7 to 13 cents per cubic yard, large contracts being taken at lower figures than small ones. Any of the dredges can excavate the larger and longer channels required for drainage at a much less cost than can be done by any other method.

SECTION AND BEHAVIOR OF DITCHES.

It has been found by experience that ditches may be constructed with sides more nearly vertical than was formerly thought practicable. In stiff loams and clays it is not desirable to cut the sides with slopes greater than 1 to 1. Ditches made with the floating dredge usually have slopes of about ½ to 1. In any case, those which carry large volumes of water change their form by reason of erosion and weathering of the earth and assume approximately the forms illustrated in figures 7 and 8, so that it is of greater importance to secure ample bottom width, in order to allow for this change, than to attempt to make the exact slope desired and expect it to remain as left by the machine.

The excavated earth, which of course lies in unsightly masses along the edges of the ditch when the work is finished, will, after weathering through one winter, assume a much less formidable shape and can in a year or two be worked down with a plow and scraper until the land can be cultivated nearly to the bank of the ditch. It is always well, however, to keep a strip on each side bordering the ditch in grass in order to prevent the banks from crumbling and to keep

the adjoining cultivated soil from being washed into the ditch in times of sudden and violent freshets.

The grades upon which such ditches may be constructed are 6 inches per mile and upward, but a grade of 3 feet per mile is required for the effectual and permanent scouring of small ditches excavated through loam or clay. Large and deep ditches, made straight and so situated that they will not receive silt or débris in large quantities will usually be self-cleaning.

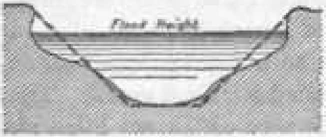

Fig. 7.—Change in section of ditch by erosion where side slopes are 45 degrees.

There are a few facts bearing upon the drainage of level lands which have been fairly well demonstrated and which, in the planning of works, should not be disregarded. One of them is that deep ditches are necessary to accomplish the desired end. By this is meant those excavated from 6 to 10 feet deep. In many instances the entire grade for lateral drainage must be made by additional depth of the outlet. The velocity and carrying capacity of the ditch increases with the depth. For example, a ditch carrying water 6 feet deep will have a mean velocity 40 per cent greater than when the water is only 2 feet deep. Water 8 feet deep will have twice the velocity of that 1 foot deep in a ditch of the same width. This partially explains why shallow ditches are such marked failures as drainage outlets. Their carrying capacity is comparatively small and their action affects only the surface of the soil.

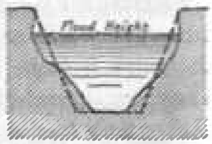

Fig. 8.—Change by erosion in section of ditch with steep side slopes.

UNDERDRAINAGE.

The history of drainage shows that a great variety of methods and materials have been employed in the work, many of them effective and all of them aiding to demonstrate its usefulness in agriculture.

USE OF TILES.

The use of drain tiles for this purpose, introduced in England about the year 1810, has increased to such an extent and the art of using them has been so perfected that the tile-drain is now regarded as the best type of underdrain. Well-burned clay pipes of circular form, 1 or 2 feet long, are laid through the soil in a continuous line upon such a grade that any water which finds its way into them will be carried by gravity to some lower point, thus conveying the surplus away. The water enters the line of tiles through openings left between the ends or "joints" as they are commonly called. The ends of the tiles should be placed close together in order to prevent the soil from enter-

ing, yet not so close as to prevent the entrance of water. The action of the tile-drain in removing the surplus water from the soil is as follows:

The drain being surrounded by soil the spaces of which are filled with water, the water in the soil flows by gravity through the crevices between the ends of the tiles, thus entering the drain, and passes off more or less rapidly, according to the grade upon which the line is laid. Other water of the soil takes the place of that removed, the water of saturation gradually passing from the surface downward, the soil near the level of the drain being the last to be relieved. The water moves downward and laterally toward the drain, and the lateral distance to which the drain will relieve the soil of water is governed by the resistance which the soil particles offer to the flow of water among them. This process does not leave the soil without moisture, but only removes the surplus. It does not, however, remove it from points below the level of the drain.

KINDS OF TILES.

The tiles used should be round in form, straight, and above all well burned. They need not be vitrified in order to be lasting, but whatever kind of clay is used in making them, every particle should be completely burned. Such a tile is then almost indestructible in earth and water. Where exposed to long-continued freezing and thawing, as at the outfalls, the best vitrified pipe should be used. After one has become familiar with the ware of a particular factory, properly burned tiles may be readily distinguished by their color and by their ring when struck with a piece of steel. Good clay may usually be semivitrified if skill is used in burning. Porosity of the finished ware is not important, since the quantity of water that will pass through the walls of well-burned tile is practically nothing. All water enters at the joints. Vitrification, although not essential, is always a desirable quality in drain tiles.

DEPTH AND DISTANCE APART OF DRAINS.

To secure efficient drainage the individual lines should be placed sufficiently near to each other for the effect of one line to reach that of another on either side so as to bring all the soil within the active range of the drains. The distance apart will depend upon the closeness of the soil, or, in other words, upon its retentive character. Soils are spoken of as "open" or "close" with respect to their drainage properties, all variations in each class being recognized and requiring drainage treatment according to their several characteristics. It follows that in practice drains are placed from 30 to 300 feet apart and from 1½ to 4½ feet deep. These various conditions can not be described

in sufficient detail to give a clear understanding of the requirements of each soil. In case of doubt regarding the proper distance apart for drains, they may be so placed that in case more perfect drainage is required a line may be laid midway between the lines. In general, close soils which consist largely of clay should have drains from 40 to 75 feet apart, and open soils from 80 to 300 feet apart. In the first instance, which is the more frequent system, tiles 2½ to 3½ inches in diameter may be used for laterals, and for the greater distance those 3½ to 5 inches in diameter should be used. It may also be said that one line of 5-inch or 6-inch tile may sometimes be used in such a way as to afford good drainage to an entire field.

Depth of drains is also a variable distance, depending upon the same soil characteristics. In some cases drains have been laid 4 feet deep with indifferent results, while drains 2½ feet deep on the same land have been attended with gratifying results. In general 3 feet is a proper depth for average soils, yet a depth of 2 or 2½ feet produces better results in some soils. Drains should be placed as deep as they will receive the water readily, with 4 feet the limit in clay and alluvial soils. Aeration of the soil is one office of the underdrain, and of great benefit to very close soils. In treating such soils it has been found beneficial to provide surface vents to the drains for the purpose of inducing a more rapid circulation of air through the drains and soil. In this way some refractory soils have been drained and greatly improved in texture. Shallow drains in such cases serve the purpose better than deep ones.

LOCATION OF DRAINS.

To begin with, there must be an outlet suitable for the system of underdrains which it is proposed to construct. A field or farm may sometimes be thoroughly drained by simply laying tiles in those parts which are uniformly too wet for profitable cultivation. This is on the theory that the other parts have sufficient natural drainage. In such cases main lines should be located in the course of natural surface flow, with due regard also to straight courses. Branch lines should follow the same general law. This does not mean that the curves and crooks which are always found in natural depressions should be followed; straight courses joined by curves should mark the lines for drains.

Land which requires drainage always lies in natural areas of greater or less size, each having one point to which all the drainage must finally come. These general areas are again divided into sub-areas, each having its outlet within the limits of the general area. The boundaries of these areas should first be determined and the plans so made that when the drainage is completed the entire tract will have been provided for. A failure to do this is a fruitful source of

disappointment in drainage work. The main drain should be located in the natural depression, with subdrains at such points as will furnish outlets for the tributary section. These are the arteries, as it were, of the whole system. This work may be carried out in two different ways. The first is to locate branch lines so as to reach those parts of the tract which are particularly in need of drainage, such as ponds, swales, sags, etc., without special regard to systematic work. This is called random field drainage. The second is to supplement the primary network by constructing laterals parallel to each other and at equal distances apart, according to the requirements of the particular soil, on the theory that every part of the field requires equal drainage.

Figure 9 shows the plan used in draining a tract of 480 acres in Iroquois County, Ill., which is generally level, but was, before drainage, diversified to some extent by ponds which contained water during six months of the year. The grades upon which the drains were laid were in some cases one-half inch to 100 feet, varying from this to 2 inches to 100 feet. The object of drainage was to fit the land at a minimum of expense for the production of hay and grains of various kinds. It should be observed that the drains were staked out in a systematic manner. As shown on the plan (fig. 9), each line is designated by some name by which it is distinguished from others. Its length, as well as its junction with other lines, is indicated by the number of feet or the station number from the outlet point in each case. This plan also illustrates various methods of location and arrangement of drains ordinarily required. The drains of this tract have been in successful operation for fourteen years and are admirably adapted to the purpose for which they were constructed. There have been no repairs or stoppages of any kind during that time. The land is an open black soil with joint clay subsoil which drains quite readily. The final outlets, as shown, are open ditches leading to the larger water course.

The most economical system for thorough drainage is that of parallel lines of a good length. This will be readily acknowledged when it is seen that, wherever one drain joins another, the soil in the vicinity of the junction has two drains acting upon it instead of one; in other words, it is doubly drained. In such soils laterals should be laid up and down the slope and not across it as advocated by many. It would doubtless seem incredible to those who find it necessary to place drains only 40 feet apart that other soils may be drained as thoroughly with parallel lines 100 feet or even 200 feet apart. In the latter case, however, the laterals should be not less than 4 or 5 inches in diameter.

While, as a general rule, drains should be laid up and down the slope, there are special cases where the other plan is more effective and will accomplish the desired end at less cost. A case of this kind

is illustrated in figure 10, which shows a pond surrounded by land with steep slopes. The subsoil of the sloping land is open and porous,

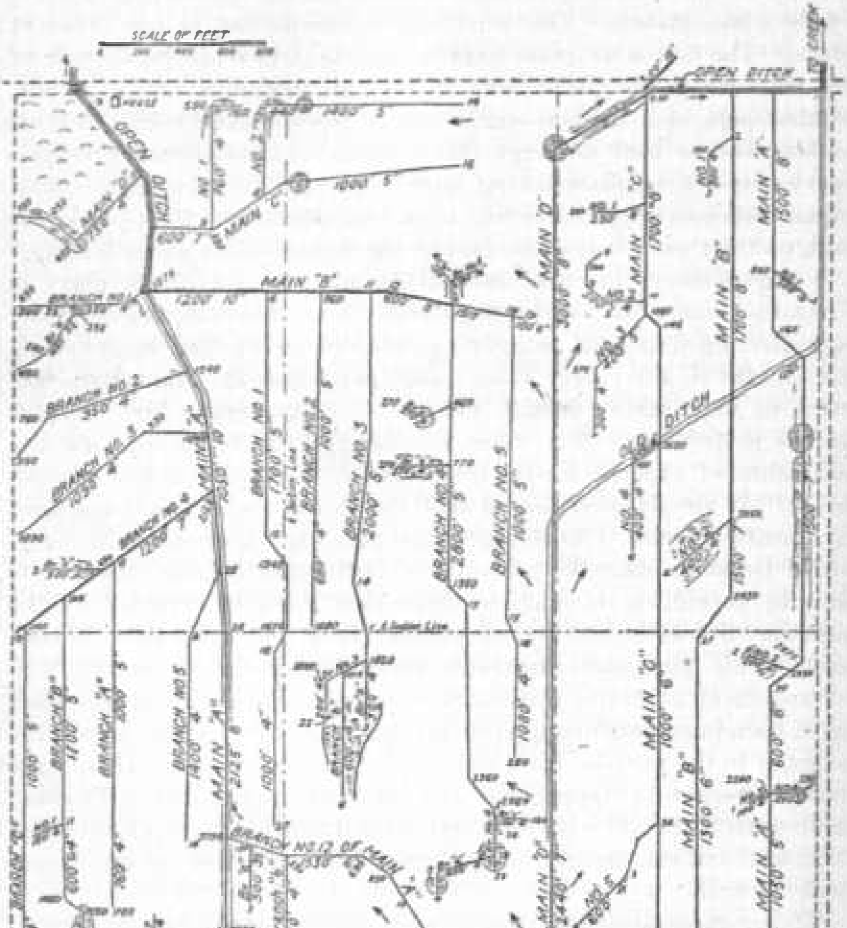

FIG. 9.—Map showing the drainage of 480 acres of land in Iroquois County, Ill., on which 69,700 feet of drain tile were laid 3 and 4 feet deep.

absorbing the rainfall readily and permitting water to flow through it to the base of the slope, where, being checked, it accumulates and

forms a border of wet ground around the outer edge of the pond. The line located through the center of the pond does not affect this wet strip, since the soil at the outer edge of the pond is less pervious to water than the soil of the hillside. By reason of this resistance and the continual head of water supplied by the hill, the base is kept saturated. An intercepting drain laid near the base, as shown in the illustration (fig. 10), is the most effective way of treating such cases. There are also long level sloughs having steep side slopes which furnish a constant supply of water by seepage at the base of the slope. Drains at the upper edge of the saturated strip will intercept the seepage water before it is forced to the surface by the pressure of the water above.

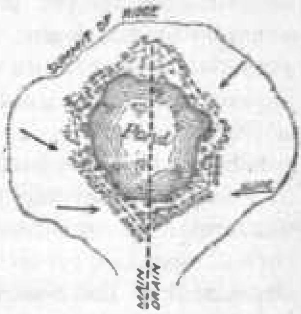

FIG. 10.—Intercepting drain.

SURVEYS AND GRADES.

Whatever may be said to the contrary, it remains a fact that in order to get the best results in a system of drainage the work should be laid out with a leveling instrument and executed in accordance with the survey made. No one can be relied upon to guess a grade correctly, nor can anyone arrange a system of grades with economy and at the same time get the best possible work out of the system without first knowing the facts as determined by the level in the hands of one who is able to use it. The drainage engineer can stake out the lines, adjust the grades, and put the work in such shape that it can be executed with precision, either by contract or day labor. The results of the work can be predicted with reasonable certainty before a ditch is opened. The drainage engineer, with the aid of the farmer who is familiar with the soil, can plan and lay out the work to far greater advantage than the inexperienced man. The farmer or superintendent can then give his attention to the execution of the work and insist on having it done according to the plans and surveys without the misgiving that it may be entirely wrong. Where there are large tracts of level land, or of land so nearly level that it can be drained successfully only by the most accurate work with instruments, the services of an engineer are indispensable. Where the land is somewhat rolling, the farmer may be able to adjust the grades himself.

The slight grades upon which lines of tiles may be laid with satisfactory results are a surprise to many; indeed, they were regarded as entirely impracticable until the experience of recent years proved the contrary. Lines of drain tiles laid on a grade as low as one-half inch per 100 feet in firm soils will operate successfully, provided the lines are not too long, while drains laid on grades of 1 to 2 inches per 100 feet may be counted by the hundreds of miles, and their successful

operation is attested by thousands of acres of cultivated lands. It is not difficult to impress upon the mind of anyone who will give the matter attention the fact that such work must be laid out with accuracy and executed with thoroughness and skill. It should be observed in this connection that the fact of a drain having a good grade should not be made an excuse for careless and inaccurate work, though it is conceded that the consequences would be less serious than where the grade is necessarily light. Where a grade can be adjusted as may be desired, 3 inches per 100 feet or one-half inch to the rod is regarded as ample for tile drains. The increase of the size of the drain as the grade is diminished is a principle that should be kept in mind in laying out work, since grades must be largely controlled by the natural slope of the land.

It is not intended here to convey the idea that drains can not be laid by guess by observing the flow of water or by the hand level, nor that apparently good work has not been done in this way; but numberless mistakes, involving great waste of labor, and failures in the attainment of the best results from the work, emphasize the wisdom of securing the best possible preliminary plans as well as their intelligent execution.

SIZE OF TILES TO BE USED.

The proper size of tiles to be used in the construction of drains is a matter upon which there is great difference of opinion, and accordingly of practice. It is doubtful if there is any part of the work requiring more careful consideration than this. Much difference of opinion on this subject arises from the fact that various soils respond differently to drainage work.

There are several questions to be considered in determining the size of tiles that should be used, especially for mains to a drainage system:

(1) What depth of water per acre will it be necessary to remove from the land in a given time, say twenty-four hours, in order to secure the desired condition of the soil?

(2) How rapidly will the water be brought to the main drains?

(3) What surface drainage does the tract have that will be available for carrying unusual rains?

(4) What is the nature of the soil as regards its drainage properties—that is, is it open or retentive?

(5) What are the grades upon which the drains must be laid?

As to the first question, it may be answered that there are times during the growing season when the entire ordinary rainfall will be taken up by the soil. At other times, when the rains are frequent and heavy and the soil becomes filled with water, it may be necessary to remove a large part of what falls in twenty-four hours. There are times when the rainfall is so heavy that the water can not pass through

the soil fast enough, even if the drains are sufficiently large to carry it off, but a part must run off the surface, by its various depressions and channels, and these it is always wise to provide.

The total rainfall varies in the different States and sections quite materially. Drainage, however, has to deal with the extremes of rainfall rather than with the mean, when the size and efficiency of drains are considered, although it is generally true that the sections having the larger annual rainfall are subject to heavier storms. There are so many unforeseen conditions to be met with that to treat the problems in an analytical way in this connection will not contribute to any clearer understanding of the best practice now followed. Laboratory experiments made for determining the relation of rainfall to drainage are often so different from field conditions that they aid us but little in practical drainage problems. Deductions from the actual working of drains in lands of varied character and in different localities give us the most valuable data upon this point, and these have been the guides used in the following discussion.

If the main drains have a capacity to remove one-half inch in depth of water from the entire tract in twenty-four hours, they afford what may be regarded as good farm drainage, for, as ascertained by observation, even one-fourth or one-third inch in that time is the limit of capacity of many drainage systems in well-improved alluvial soils. The soil is a great reservoir and will hold from 25 to 40 per cent of its volume of water. In localities where no advantage can be taken of the surface flow for relief in times of heavy rainfall, mains may be used large enough to carry off 1 inch of water in twenty-four hours. Ordinarily for lateral drains no smaller than 3-inch tile should be used, and for open soils, where lines may be placed 100 feet or more apart, no smaller than 4-inch tile should be used.

The capacity of drains for carrying water may be computed quite accurately, but the modifying conditions and the quantity of water it is desired to remove in a given time are just as important elements in any determination of the problems. Any table which can be computed will apply only to the conditions assumed, whereas each drain presents a problem which should be solved with all its peculiarities considered. The following table has been computed to serve as a guide in adjusting the size of mains to the area which is to be drained. Two cases only are considered—one in which the mains are 1,000 feet long, and the other in which they are 2,000 feet long. Lateral drains should be 3 inches and 4 inches in diameter. Submains or large branches which themselves receive the drainage of laterals should be regarded as mains in considering their size. The table is computed for removing one-fourth inch of water in depth each twenty-four hours from the area drained. Should the conditions be such as to require the removal of a greater depth of water in twenty-four hours, a proportional reduc-

tion in the number of acres given in the table may be used; that is, if it is desired to remove one-half inch of water instead of one-fourth inch, the sizes given in the table will serve one-half the number of acres. If it is desired to remove only one-eighth inch the sizes given in the table will serve twice the number of acres indicated.

Areas from which one-fourth inch of water will be removed in twenty-four hours by outlet tile drains of different diameters and different lengths with different grades.[a]

Diameter of tile in inches.	Grade per 100 feet in decimals of a foot (with approximate equivalents in inches).											
	0.04 (½ in.).		0.06 (¾ in.).		0.08 (1 in.).		0.10 (1³⁄₁₆ in.).		0.12 (1½ in.).		0.16 (2 in.).	
	Length of drain in feet.											
	1,000.	2,000.	1,000.	2,000.	1,000.	2,000.	1,000.	2,000.	1,000.	2,000.	1,000.	2,000.
	Acres of land drained.											
5	17.3	13.5	17.7	14.0	19.1	15.7	19.8	16.7	20.6	17.6	22.1	19.4
6	27.3	21.4	28.0	22.2	29.9	24.8	31.2	26.4	32.5	27.8	34.8	30.5
7	39.9	31.4	41.1	32.7	44.1	36.4	45.9	38.7	47.7	40.8	51.1	44.8
8	55.7	43.7	57.3	45.6	61.4	50.7	64.0	53.9	66.5	57.0	71.2	62.6
9	74.7	58.8	76.5	61.2	82.2	68.1	85.6	72.3	89.1	76.3	95.3	83.8
10	96.9	76.3	99.5	79.5	106.7	88.5	111.2	94.0	115.6	99.2	123.9	108.9
12	152.2	119.9	156.1	124.9	167.7	139.3	174.8	147.9	181.7	156.2	194.6	171.6
14	222.8	175.9	228.7	183.7	245.3	204.3	256.1	217.4	265.8	229.7	284.9	251.7
16	310.2	245.0	317.8	255.9	341.4	284.6	355.4	302.5	369.5	319.7	396.3	350.4
18	414.4	328.7	424.9	342.5	456.4	381.3	475.7	405.5	494.4	428.1	529.1	470.1
20	537.6	426.9	551.6	444.9	591.5	495.8	616.4	526.7	640.4	556.6	686.3	610.5

Diameter of tile in inches.	Grade per 100 feet in decimals of a foot (with approximate equivalents in inches).											
	0.20 (2⅜ in.).		0.25 (3 in.).		0.30 (3⅝ in.).		0.40 (4¾ in.).		0.50 (6 in.).		0.75 (9 in.).	
	Length of drain in feet.											
	1,000.	2,000.	1,000.	2,000.	1,000.	2,000.	1,000.	2,000.	1,000.	2,000.	1,000.	2,000.
	Acres of land drained.											
5	23.5	20.9	25.1	22.7	26.7	24.5	29.5	27.5	32.0	30.3	37.7	36.3
6	37.0	33.0	39.6	35.9	42.0	38.6	46.4	43.5	50.5	47.8	59.4	57.3
7	54.3	48.5	58.0	52.8	61.6	56.7	68.2	63.8	74.0	70.1	87.1	84.1
8	75.6	67.7	80.9	73.6	85.8	79.0	95.0	89.1	103.3	98.0	121.4	117.3
9	101.4	90.7	108.4	98.6	114.9	106.0	127.0	119.4	138.1	131.3	162.6	157.1
10	131.6	117.9	140.6	128.1	149.3	137.6	165.2	155.3	179.2	170.5	211.1	204.4
12	206.8	185.6	221.1	201.8	234.5	216.9	259.2	244.1	281.8	268.6	331.8	321.7
14	302.5	272.2	323.5	296.1	343.5	318.1	379.7	358.2	412.9	393.9	485.8	472.1
16	420.6	379.1	449.9	412.2	477.4	442.9	527.8	498.4	573.7	548.8	675.2	657.3
18	562.2	508.1	601.8	552.5	638.1	593.7	705.2	668.0	767.4	735.1	902.3	880.5
20	729.2	660.3	780.0	718.2	826.9	771.1	914.7	867.8	994.5	954.6	1,170.1	1,144.1

[a] This table was computed from the formulas for determining the size for tile drains given in Elliott's Engineering for Land Drainage, which are:

$$(1)\ v=48\sqrt{\frac{d(f+\frac{1}{2}k)}{l+54d}}$$

$$(2)\ Q=av$$

$$(3)\ A=\frac{Q}{.0105}$$

Where v=velocity of flow in feet per second.
a=sectional area of tile in square feet.
d=diameter of tile in feet.
f=total fall in length of drain.
k=depth of drain in feet at upper end.
l=total length of drain in feet.
Q=discharge of drain in cubic feet per second.
A=acres drained.
Constant 0.0105=quantity of water to be removed from 1 acre in 1 second of time.

Computations are made for two assumed lengths of drain—1,000 feet and 2,000 feet. $\frac{1}{2}k$ is 1.5 feet, that is one-half of depth of drain where the soil is open and saturated with water, under which conditions the drain will discharge its maximum quantity. Where the soil is close no additional head will be added by the free water of the soil, so that the factor $\frac{1}{2}k$ should be omitted in computations. Three feet of soil above the top of the drain has been assumed. It will be readily seen that the grade, length of drain, and openness of soil are important factors in the capacity of a tile drain for discharging soil water.

In the use of the table for determining the size of drains, good judgment must be exercised in applying it to the case in hand. The tract under consideration may have such surface slopes that the underdrains may be called upon to take the drainage of a much larger area than if the land were nearly level. By reason of the surface slope and drainage a main may be required to receive the drainage of 20 acres instead of 10, as would appear at a casual glance. It is important to take into account also all the facilities for natural drainage when one undertakes to drain land by tiles. Too large tiles involve an expense without adequate return, while those which are too small may entail an annual loss that will soon equal the amount that was apparently saved in their purchase.

The present tendency in drainage is to use large tile mains in place of small open ditches where land is worth $200 an acre or more. It is not uncommon to use tiles 18 and 20 inches in diameter. Where large tracts are drained some surface relief drains should also be provided against excessive rainfall in order to keep the expense of the main underdrains within the limits of paying returns.

DIGGING THE TRENCH.

The trench should be started on the surface by a line and should be made clean-cut and straight. Any curve made at the surface will ordinarily be greater when the bottom is reached. If a survey has been made, a line should be drawn about 5 inches to one side of and parallel with the line of grade stakes. It is assumed that these stakes have been set on a true line 50 or 100 feet apart and that the depth of the cuts from the top of each grade stake to the grade line of the ditch has been furnished to the workman or marked upon the guide stakes which denote the position of the grade stakes.

FIG. 11.—Grading scoop.

The digging tools which are necessary in easily worked soils are as follows: A ditching spade with blade 18 or 20 inches long, a round-pointed shovel with long handle, and a grading scoop of the "pull" pattern (fig. 11). In light, mucky soils a muck spade, which is a three-tined fork with a steel cutting edge like a spade, can be used with profit. Where the clay is hard or stony a pick and iron bar will be necessary. Straight ditches and neat work should be insisted upon, since the labor required is no greater than in digging crooked and ragged ones, and a drain in a neat line is more efficient than one which has short irregular crooks. Where it is necessary to change the direction of the line it should be done by an easy curve. When a lateral drain joins another it should form an angle of about 30° with it.

The most essential thing about a trench for a tile drain is the finish and grade of the bottom. When only light grades are possible the lines should be staked out and leveled as before indicated. Many failures in the action of tile drains have resulted from neglect or carelessness in this matter. Many farmers have drained successfully where the fall was 1 foot or more per 100 feet, because it was hardly possible to grade the line so that it would not have fall in every part and because the fields were small and the work simple. Such men sometimes advise freely against the use of the level and the labor involved in laying out the work and computing the grades carefully. It is true it does not follow that because the work is carefully laid out this is in itself a guaranty of success, but the work must be properly carried out, and that requires a knowledge of how to do it. It is claimed that water is the best possible guide for grading the bottom. It is true that where water will flow in a trench it will flow in the drain after the tiles are placed; but much of the drainage work on level land must be done when there is no water in the soil to guide the workman. Even where there is water long lines on light grades can not be carried to distant fields with any assurance that the desired grade and depth will be secured, unless levels have been previously taken and depths determined.

GRADING THE DITCH FROM A SURVEY.

In making the survey of a drain, short stakes are set at intervals of 50 or 100 feet about 18 inches from the center line of the proposed drain. The grade is computed and the depth determined by the surveyor, which is to be measured from the top of each stake. These figures, if the work has been done correctly, will be all that are necessary for the workman to use in constructing the ditch.

There are several methods of accurately grading a ditch from a survey, all depending upon the same principle. The line-and-gauge method, although open to some objection, is more easily understood by workmen of all classes than any other, and will be here described. It consists in setting a line or fine wire directly over the grade stakes at a given distance above them and parallel to the bottom of the proposed ditch. Some convenient distance above the bottom of the ditch is chosen, as, for instance, 4, 5, or 6 feet, and a light line (fig. 12, *e*) is set parallel to the required bottom (*f*). When the line is first drawn, temporary stays may be placed under it to prevent sagging. A gauge rod (*a*), with a light arm (*b*) placed upon it at right angles at the constant height for which the line is set, is the implement by which the work is tested. To determine the height at which the line should be set above each stake (as *c* and *d*), subtract the depth of the ditch at that point from the length of the gauge, or the height of the line above

the specified grade. The remainder is the distance above the grade stake at which the line should be set. As the bottom is graded, it should be tested by holding the gauge in a vertical position with the foot resting upon the floor (*f*) of the ditch. When the lower edge of the arm (*b*) touches the line, the ditch is at grade at that point. A small level fastened upon the arm (*b*) will aid the workman greatly in holding the gauge rod in a vertical position.

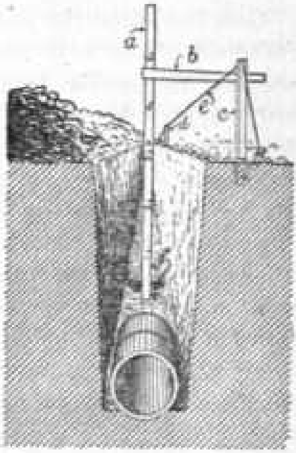

FIG. 12.—Grading by line and gauge.

Begin at the lower end to excavate the ditch. No grade line need be set up until all excavation except the bottom has been done. Then set the gauge line and take out the last or bottom spading to the proper depth as nearly as may be judged, working backward and taking care to not dig too deep. When a length of 4 feet or thereabouts has been excavated, use the cleaning scoop to clean out the crumbs and to dress the bottom. While doing this the workman should stand on the bench one spading above the bottom, and grade the trench by pulling the cleaning scoop toward him. Test the finished ditch with the gauge, and, if not deep enough, dress the bottom with the cleaner until it is correct. It is then finished and ready for the tiles. If the ditch is intended for a tile larger than 8 inches in diameter, the grading is done with a round-pointed shovel, the workman walking on the finished bottom. Where the soil is too hard to spade readily and the pick must be used in finishing the excavation, the workman will necessarily work upon the floor of the drain.

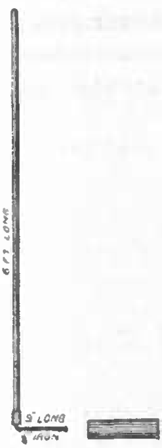

FIG. 13.—Tile hook.

LAYING THE TILES.

After the bottom of the ditch has been prepared, the tiles should be laid from the outlet upgrade. Sizes up to 8 inches in diameter may be conveniently laid with a tile hook (fig. 13), the workman standingon the bank of the ditch and reaching the tiles into place, turning them in the trench until their ends fit closely together along the top line. When this has been done there is ordinarily a space between the ends of the tiles along the bottom or base, owing to the fact that in their manufacture tiles are not usually cut with parallel ends. The advantage of starting the ditch straight and keeping it so will now be appreciated. In making curves the straight tiles can be used by turning them around until

they fit the desired curve. In case a crack of one-fourth inch or greater is left, it should be covered with a piece of broken tile. Junction tiles should be set where laterals are to enter, and these should be Y's in preference to T's.

However close the joints may be made with tile, as ordinarily manufactured, there will always be sufficient space for the entrance of water. In case the bottom of the trench is in fine sand or silt filled with water, there may be danger of material passing through the joints into the tiles. To prevent this put clay or turf upon the joints, or place a small strip of tarred building paper over them. In ordinary clay or loam there need be no fear entertained that the tiles will fill

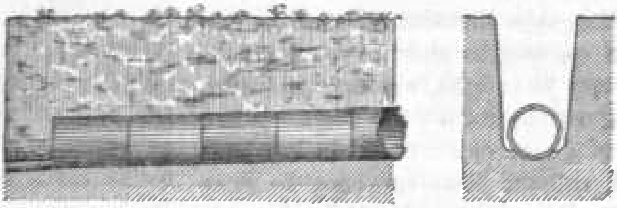

FIG. 14.—Large tile main in place.

with solid matter if they have been properly laid. If care be exercised in the construction of the entire system of tile-drains, its successful operation can be assured.

Where a soft bottom is encountered of such a nature that the tiles will not remain in place, a board 1 inch thick should be used in the bottom of the ditch upon which the tiles may be laid. Sewer pipe in lengths of 2½ or 3 feet with bell ends may often be used in such places with better results than short tiles. Figure 14 shows a large tile main in place.

FILLING THE TRENCHES.

Enough earth should be thrown upon the tiles after they are laid to secure them in their position. This work should be intrusted to a careful workman, who should see that moist earth is thrown around and over the tiles in such a way that they will not be moved by any subsequent filling. After this has been done the filling may be completed in the most convenient and expeditious manner. Where the land is cultivated, ditches can be filled rapidly with a plow pulled by a team on each side of the trench. The evener used upon the plow for this purpose should be 16 feet long. The excavated earth, it has been assumed, has been thrown in about equal quantities on each side of the ditch. In meadow or sod land a V-shaped scraper with the point behind, made for the purpose, can be used to fill from both sides at one passage without disturbing the turf. In order to use either of these methods satisfactorily the earth should be dry enough

to fall apart when moved, instead of sticking together in a gummy mass. Where the soil is too wet, soft, or sticky to be moved by the means just described, the filling may best be done by hand labor with a potato hook, or filling hook, which is in the form of a hoe with tines instead of a solid blade. The land should be cultivated the next year or two after being cut up by drains, if practicable, because the earth is loose and continues so for a year, preventing grass from taking quick and permanent root. This is not the case with cultivated crops, as the most luxuriant growth may usually be found directly over the drains.

DITCHING MACHINES.

During the sixty years in which tile drainage has been practiced in this country, many machines for opening the trenches for tile have been invented and manufactured, which, when tested, failed to meet the requirements. There are many difficulties to be met in the digging of farm drains. The soil is often soft and sticky; at other times it is hard, and in some localities contains gravel, stone, and hardpan. Deep cuts must sometimes be made; muck ponds and shaking bogs must be gone through. In short, the difficulties to be overcome by the inventor of a tile-ditching machine can hardly be appreciated by any one unacquainted with practical draining.

Doubtless no machine will ever be made that will meet the requirements of all kinds of land. There are, however, a few which seem to work satisfactorily where the ground is sufficiently firm to support the machine and where the earth is not extremely mucky and sticky. Where draining of considerable extent is proposed, the adaptation of these machines to the work required may be profitably investigated.

SOME OF THE RESULTS TO BE EXPECTED FROM UNDERDRAINS.

After heavy rains the surface usually begins to dry first directly over the drain, the drying process extending on either side until the limit of action of the drain is reached. This limit, as previously explained, will depend upon the closeness and structure of the soil. The physical characteristics of the soil also affect in a remarkable degree the quickness of the action of drains, so that their effect as regards both time and extent varies greatly with the kind of soil acted upon. Nevertheless, there are but few soils which will not respond to underdrainage if properly treated.

The farmer may reasonably expect to begin working his land a week or ten days earlier in the spring with the soil in good condition than if it were not drained. He may expect that his winter grain and clover will not be injured by the heaving of the soil, as is the case with wet clay soils. He may expect his crops to endure the drought of summer with less injury than those on undrained land. He may

adjust the rotation of his crops irrespective of the fact that some portions of the field are wet while others are dry. He may continue his cultivation during the summer without being obliged to avoid or go around portions of the field which, by heavy rainfall, are made too wet for profitable cultivation.

COST AND PROFIT OF TILE DRAINAGE.

The ultimate question that must be answered in regard to drainage is, "Will it pay?" The agriculturist can usually answer that question if he can ascertain what the cost of the work will be. From what has been said regarding the necessity of varying the distance between drains to accomplish the same work in different classes of soils, it will be seen that the cost must necessarily vary greatly. The price of labor and material in different sections of the country is also subject to constant change. Farms of which parts have natural drainage and parts require artificial drainage may be improved at a cost of $6 to $8 per acre for an entire farm where the outlets are provided by nature. In this case the improvement consists in draining the wet land and fitting it for profitable cultivation. On farms which require drains at uniform distances of, say, 100 feet, the cost may be $14 per acre, while on those lands requiring drains 33 feet apart the cost will be $22 to $30 per acre. The cost will vary, of course, according to the price of material and labor.

Tiles are sold by the thousand feet, each tile being 1 foot long except sizes above 12 inches in diameter, which are usually made 18 or 24 inches long. The prices given below are those prevailing in the East and Middle West. Prices in the far West are quoted much higher than those here given. The following may be regarded as an average range of prices for tile at the factory, and in some instances at a railroad station 100 miles distant from the factory:

Cost of tiles of different sizes per 1,000 feet.

3-inch tiles	$10.00 to $12.50
3½-inch tiles	12.00 to 15.00
4-inch tiles	15.00 to 20.00
5-inch tiles	20.00 to 27.00
6-inch tiles	27.00 to 35.00
7-inch tiles	36.00 to 50.00
8-inch tiles	45.00 to 60.00
10-inch tiles	60.00 to 110.00
12-inch tiles	90.00 to 150.00

The excavating of the ditches is done by workmen who furnish their own tools and contract to dig and grade the ditch, lay the tiles, and cover them securely with a few inches of earth, at a certain price per rod. The price of such work in soils which may be easily handled with the spade, that is, those having no stones and not so hard as to

require the use of the pick, is about 25 cents a rod for ditches averaging 3 feet deep and for tile not exceeding 6 inches in diameter. Such ditches may range from $2\frac{1}{2}$ to $3\frac{1}{2}$ feet deep, making an average of 3 feet. Where the range is from 2 to $2\frac{1}{2}$ feet, 20 cents a rod is considered a fair price. For depths from 3 to 5 feet an additional price of 1 cent per rod for each inch of depth below the average of 3 feet is charged. That is, a ditch averaging $3\frac{1}{2}$ feet deep, will cost 31 cents a rod; one 4 feet deep, 37 cents. It is the practice of workmen to accept the average depth of the entire line as the depth upon which settlement for the work is to be made. For tiles 8 to 12 inches in diameter, the price is 30 cents for the 3-foot depths and $1\frac{1}{2}$ cents an inch per rod for additional depths.

These statements should serve as a general guide only in making estimates. The hauling and distributing of tile and the tough and hard clays encountered in many localities will necessarily make considerable variations in the cost of completed drains. The farmer may often do much of the work with the labor he regularly employs at a less cost than the price a contractor will make, especially if the drains are to be laid in hard or stony soil.

The profit derived from draining wet land is more apparent when we consider that the same labor that is bestowed upon undrained land will produce from 20 to 50 per cent greater yield of cereals where the land is drained. As a rule, lands to be drained should have a large supply of fertility, drainage being the only thing needed to make them productive. It has, however, been found by experience that soils which require artificial fertilizing frequently become very productive when drained, since the fertilizers applied are able, through the effect of drainage upon the soil, to bring into use natural resources hitherto hidden and unavailable.

The writer has known of many thousands of acres of land that have been drained, and has never known of an instance in which the money spent for drainage, when thoroughly done, did not pay a large return on the investment. An annual profit of 25 per cent is not at all uncommon. The question should be looked at in the following way: If the farmer owns the land he must pay the taxes, keep up the improvements, and procure the necessary help and implements for cultivating it. If there is land which he cultivates at a disadvantage, because it is too wet to yield a full crop, or possibly yields none at all, proper drainage will cause this land to yield a full crop without the expenditure of any additional labor, seed, or capital, and the entire increase may properly be regarded as the profit of drainage. A few examples which have come under the writer's personal observation will help to emphasize these general statements.

A 20-acre field which usually yielded only 25 bushels of corn per

acre was tile-drained at a cost of $10 per acre. The yield after drainage was not less than 60 bushels of corn per acre, and the yield of

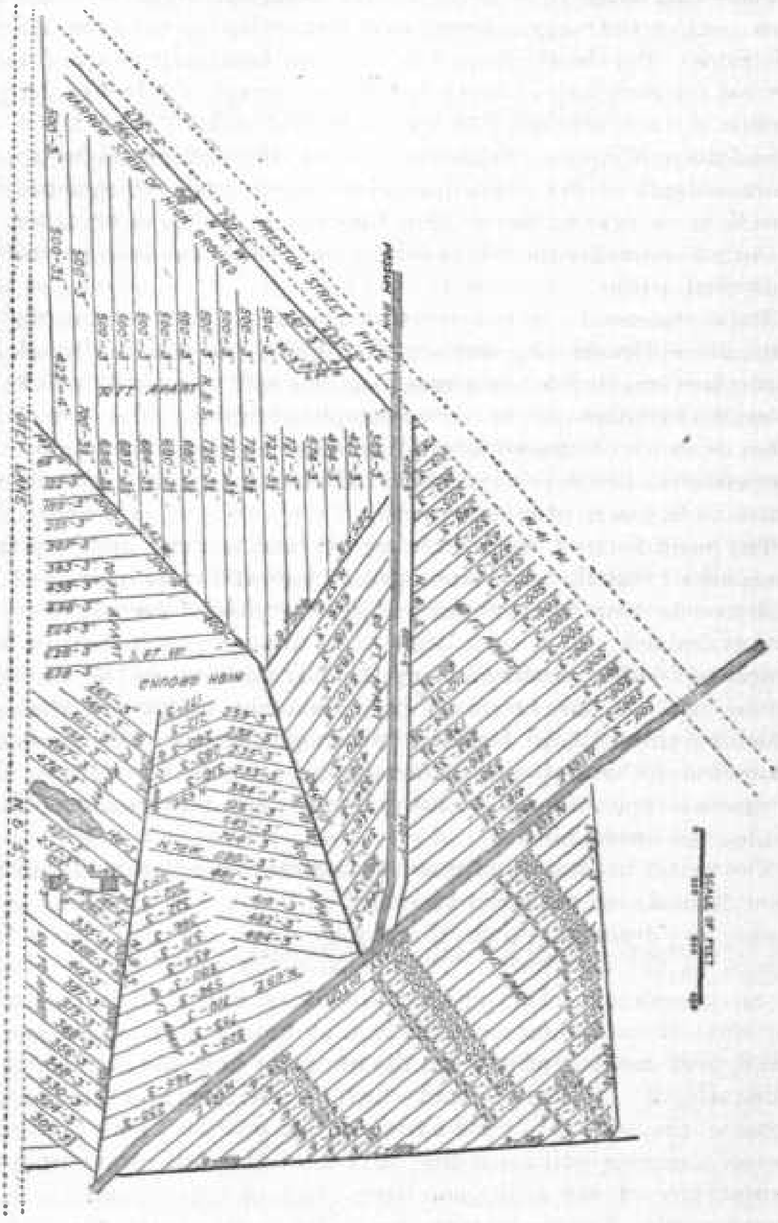

Fig. 15.—Map showing the drainage of 125 acres of clay land in Jefferson County Ky.

other crops in the rotation was in proportion. This gain of 35 bushels, at 30 cents per bushel, the selling price of corn at that time, paid for the entire cost of drainage the first year.

A pond, previously waste land, was drained at a cost of $8 per acre. It was broken and sown to millet, and the first crop paid the expense of underdrainage.

A farm of 160 acres situated in an Illinois drainage district was taxed $5 per acre for the general outlet. It was bought for $30, subject to this tax of $5, costing the purchaser $35 an acre. Tile drainage and improvements cost $15 per acre, making the land cost $50 per acre. The farm was rented and yielded the owner a rental of $5 per acre for four successive years, or 10 per cent on the entire investment. He was then offered $80 per acre for the farm and refused it.

As will be noticed in comparing the two maps of drainage given on preceding pages, there is a material difference in the method of treatment necessitated by the differences in soil. In the Kentucky plan (fig. 15) the drains are placed systematically 50, 60, and 70 feet apart, the entire cost of the work being $25 per acre. The plan of the Illinois work, where the soil possesses better drainage properties, was made with special reference to the particular requirements of the land in connection with natural drainage, and the work cost about $9 per acre. The drains in both plans have been in actual operation for several years and are evidently well adapted to the needs of the respective localities.

It is a well-recognized fact that no practical gardener or fruit grower attempts to practice intensive cultivation on land which is not fairly well drained, either naturally or artificially. It would be easy to multiply examples of the profits which accrue from the practice of soil drainage, not only to the farmer who drains his land and cultivates it himself, but also to the capitalist who purchases land which is comparatively worthless without drainage and then improves it in this way as an investment. What has been said, however, will be sufficient to indicate that nothing brings a surer return for the money invested than does the drainage of rich soils.

CATCH BASINS AND PROTECTION OF OUTLETS.

Surface water should be excluded from tile drains unless sufficient provision is made for conveying it into them in such a way that dirt, sand, and rubbish will be prevented from entering. This may be done by the use of catch basins constructed of two lengths of sewer pipe set in a vertical position (fig. 16) and covered by an iron grating (*a*) to prevent rubbish entering the drain. This grate may be covered with a pile of bricks or small stones (*b*) to act as a coarse filter and prevent the clogging of the grate. The bricks or stones may be rearranged and the silt removed from the bottom of the basin occasionally so that with proper care such an arrangement will serve an excellent purpose for removing surface water from places where it can

not pass through the soil with sufficient readiness and at the same time do no injury to the drain. Such basins should not be connected with drains of less diameter than 6 inches. Under the conditions which make it desirable to use them, the surface water will be received and pass away before the soil water reaches the drain.

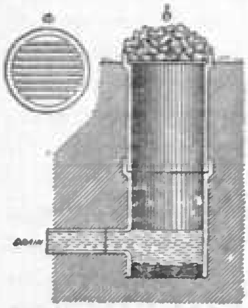

FIG. 16.—Catch basin for leading surface water into a tile drain.

While a substantial stone or brick bulkhead at the outlet of each main drain, when well made, has a permanent and workmanlike appearance, it is expensive and in many localities impracticable to use because of the lack of proper material. One of the most common as well as most efficient protections is the plank box with wire bars placed vertically across the end about 2 inches apart. Such a box (fig. 17) should be made of 2-inch plank, 12 feet long and large enough to admit of the insertion of the tile into the upstream end. It should be laid correctly, and more than ordinary care should be taken in tamping the earth securely about it. In fact, the entire filling should be well tamped from bottom to top. A protection of this kind serves two purposes: It prevents small animals from entering the drain, which they are likely to do when no water is flowing from it, and obviates the necessity of using vitrified tile at the outlet, which it is always wise to do for the reason that red tiles usually scale when exposed to the weather under such conditions.

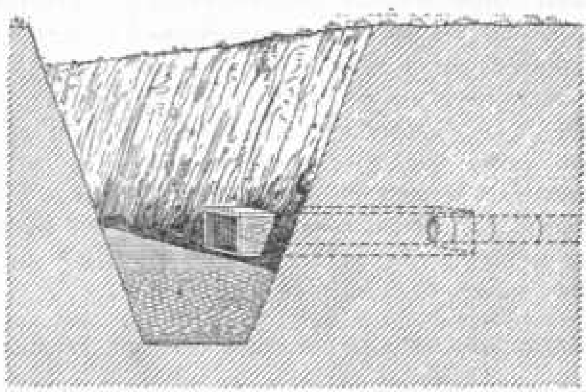

FIG. 17.—Outlet protection for drains.

OBSTRUCTION OF DRAINS BY ROOTS.

As far as known, the roots of grains, grasses, and annual field crops do not obstruct underdrains, but this is not the case with the roots of some trees. Among them are the willow, water elm, tamarack, and

sometimes the soft maple, which in a short time will fill the drain with a mass of root hairs, even when they are growing 50 feet distant from the line of the drain. It should be noted that our field drains under ordinary conditions contain no water during a considerable portion of the growing season. Those drains which are fed by springs or have a continual flow through them are more subject to obstruction from the roots of trees than drains which are dry for a part of the year. Dr. W. I. Chamberlain, of Summit County, Ohio, in writing upon this subject, says:

I have lately dug down to my drains in an apple orchard set twenty-one years ago with trees 33 feet apart, and whose roots long since met and passed each other and whose branches have nearly met, and the drains placed between the rows are wholly free from any obstruction by roots.

An orchard known to the writer was set on the farm of Mr. L. Goodwin, in Tipton County, Ind., thirteen years ago, consisting of apple and pear trees in rows 30 feet apart. Tile drains were placed 5 feet deep between the rows and as yet are unobstructed by roots. The tiles in a small fruit garden adjoining this orchard, drained in a similar way, are still free from roots.

Where there is reason to suspect that there will be difficulty with tree roots the joints of the tiles near the trees should be securely cemented. It is safe to say that all willows and water elms growing within fifty feet of any tile-drain should be destroyed, irrespective of the flow of water in the drain.

COOPERATION IN DRAINAGE WORK.

It is not often the case that drainage can be accomplished in any comprehensive manner without cooperation among landowners. Outlets can not always be secured upon the land which it is desired to drain. Water courses exist without reference to land lines or the desires of individual owners. The property of some owner is more elevated than that of an adjoining neighbor, and as a result the lower land, in a state of nature, receives the drainage. All land is entitled to such drainage relief as is afforded by nature. When natural means are insufficient and cooperation becomes necessary, there are common interests involved which can not be considered separately. Both mutual and individual benefits should eliminate self-interest sufficiently to secure a fair consideration of the merits of the case in hand. It may be said that the improvements made by any farmer in a community indirectly benefit his neighbors. The privilege of improving his land by draining it should not be prohibited either by law or the prejudice of his neighbors, especially when no injury can be suffered by the neighbor occupying lower land. Assuming that the owner of land occupying a higher level desires to drain, and has no outlet without crossing the

land of his neighbor, he should not be enjoined from doing so at his own expense, even when no good will incidentally be conferred upon that neighbor. On the other hand, if the drain so constructed will benefit his neighbor, the latter should bear a proportional part of the expense of the work done on his own land. A case can scarcely be found where the making of a drain for the benefit of upper land and conducting it through that occupying a lower level can work any injury to the lower land. It is in accordance with justice and equity, however, that the work of improving the upper land by artificial means should be done in such a way that no injury will result to anyone. In case this is unavoidable, remuneration should be made to the person suffering injury. Some farmers are unintentionally captious in cases where the improvement of a neighbor's land requires some concession on their parts. At the same time there is great reluctance on the part of some to consider the rights of the owners of lower lands over or through which drainage must be obtained. Many misunderstandings in the adjustment of these matters arise from a misconception of the true office and results of land drainage in general. It is a subject whose appearance varies according to the view point of the observer, and so requires candid consideration by every one interested in carrying out work of a character covering more than individual interests. The questions arising under this head are so diverse and include work of such magnitude that a comprehensive knowledge of the subject is a necessary prerequisite in arriving at any just conclusions.

DRAINAGE OF IRRIGATED LANDS.

The soils in most irrigated regions are deep and loose, containing a small percentage of clay, but rich in available plant food. They are finely divided, and possess great capillary attraction for moisture; moreover, their physical structure is such that they are easily kept in perfect condition by judicious cultivation. Further than this, they permit of the ready passage of water through them after the capillary spaces have been filled. The rainfall is so far deficient that water must be obtained from supplies diverted from mountain-fed streams, brought to the land, and distributed by ditches. The effect of this application of water to soils, under judicious management, is remarkable, as the abundance and value of the products obtained from such land have proved. The irrigator applies water by surface flooding, using such quantities as his judgment and experience may dictate, feeling sure that any excess which he may apply will speedily pass down into the earth which, under primitive conditions, being dry to a depth of from 40 to 60 feet, porous and open, affords unlimited drainage facilities. The large amount of leakage from main canals and the surplus from overirrigation for a time find a ready and harmless exit into the lower

soil. Under such conditions the under strata become a waste reservoir which receives by percolation the leakage from irrigation canals and the drainage from overirrigation, thus securing to the cultivator as perfect soil conditions as could be desired.

Many of these soils contain considerable quantities of soluble (alkali) salts, prominent among which are sodium chlorid, sodium sulphate, and sodium carbonate, which originate in the rocks from which the soils are formed. Lands which up to a certain time have produced crops in quantity and quality to which no exception can be taken may, without apparent cause, begin to deteriorate. Upon examination it will be found that the alkali salts have accumulated near the surface in such strength as to destroy crops that had previously been grown successfully. Upon further investigation as to the cause, it is found that the water in the lower soil has dissolved large quantities of alkali and holds it in solution. The rise of water to a plane at or near the surface from which rapid evaporation takes place results in the deposit in solid form of all the alkali contained in the water evaporated. The active capillary power of the more finely divided soils accelerates the upward movement of the water, the evaporation of which is rapid in arid climates, resulting in a deposit which constantly increases from year to year.

The presence of layers of hardpan at irregular intervals throughout the upper 6 feet of the soil, as well as occasional layers of gravel deposit and adobe clays, has had much to do with the deflection and concentration of soil water. By reason of hardpan layers, the excess of water is brought to the surface more directly at some points than at others. Under the action of soil water, some varieties of hardpan soften and gradually disintegrate, thus changing the general texture of the soil where it exists. The need of drainage of such soils as a preventive of the injuries noted, as well as for the restoration of land to its normal productive condition, is appreciated. It is not proposed here to discuss at length the varying conditions existing in different localities, but to call attention to the success that has attended the efforts of some farmers who have reclaimed land from the effects of seepage and alkali.

In the treatment of lands of this character it must be remembered that the conditions under which land becomes saturated by seepage are radically different from those of rainfall. In irrigated lands the water accumulates at various points by underflow from the waste of irrigation practiced upon more elevated land adjoining, or from leakage of supply ditches which are constructed through pervious material. The prevention of the accumulation of water in harmful quantities is best accomplished, not by its removal from the soil after saturation of the land, but by intercepting it before it reaches the lower level. A

few examples of this kind will indicate that the method most successful differs quite materially from that used in humid areas.

Albert Igo, near Greeley, Colo., has used a series of small wells located at points where water appeared, sinking them into the gravel which lies beneath the saturated soil. The wells consist of curb boxes 12 inches in diameter, made with eight sides, from boards 1 inch thick. They are sunk from 8 to 12 feet deep, the excavations being made with a large auger. The wells have underdrain outlets about 3 feet deep, leading to a surface ditch. The water rises at once in these wells to the height of the outlet provided and flows away. The soil, which is about 5 feet deep, is underlaid with gravel, which through the process of seepage from higher lands has become surcharged with water which by reason of constant pressure and continual supply from land occupying a higher level saturates the soil above the gravel. These wells, put in at various points where water appeared, reclaimed at small cost a field which had been given over to grazing land on account of the saturation and alkali.

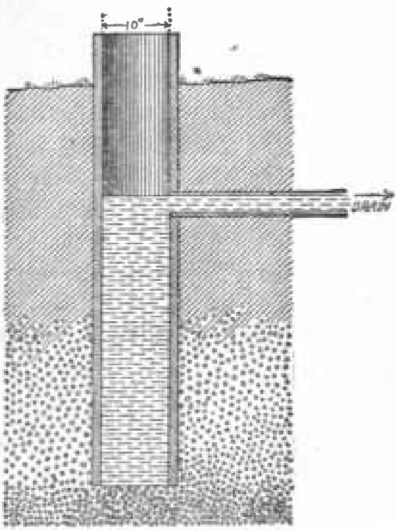

FIG. 18.—Drainage of irrigated land by wells.

This method of draining is regarded as highly successful by the farmers of the vicinity who have witnessed the reclamation of the land so treated. The individual well and drain as used in the work described are shown in figure 18. The method is simple. Its efficiency consists in relieving the pressure of the underground water at such a depth that it will not continue to force itself upward against the soil, and also in removing such a quantity that the gravel stratum underlying the tract will provide for the remainder.

Drains upon another plan have been used by J. Hetzel and others in the vicinity of Longmont, Colo. A continuous line of underdrains is laid crosswise of the slope along the upper border of the lands showing seepage. These drains are laid 5 feet deep, which is regarded as necessary to their success. The subsoil is adobe clay, in which pockets of sand are encountered which interfere with the laying of the drains. The method of location is shown in figure 19. The drains are made of 1-inch boards in the form of a continuous box, 6 by 6 inches in the inside, with no bottom. These drains, complete, cost about $1 per rod. It is not uncommon in this vicinity to find one drain located in this

manner intercepting sufficient water to reclaim 40 to 80 acres of land, where the soil is of a stiff nature. Where soils are open and admit of very free percolation of water the same plan is applicable, but the size of drains must be increased. The quantity of water which it is necessary to intercept is greater than is usually suspected, and some failures to obtain good results are probably owing to the fact that the drains are too small. Shallow drains do not accomplish the desired result, nor do drains laid up and down the slope accomplish the work as fully and cheaply as those laid across the slope.

Where drains are laid in wet land its unstable condition and water-bearing sand pockets often make it impracticable to use short tiles unless laid upon a broad base. Sewer pipes known as "seconds" may sometimes be used in place of drain tiles with better success because of their greater length and the addition of sockets which aid in holding them in alignment.

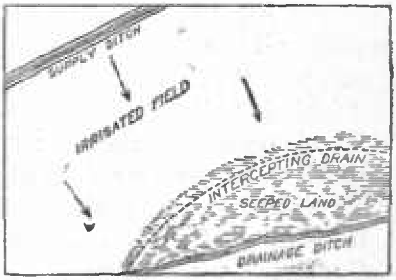

FIG. 19.—Drainage of irrigated land by intercepting drains.

The plans of treating land for the purpose of redeeming it from alkali which has accumulated through evaporation and seepage are not uniform, nor is there any practice which has been so reduced to a system as to justify an authoritative statement of methods that may be best employed. The cutting off of the underground supply by drainage has often resulted in the full reclamation of the land, with no other treatment than subsequent irrigation and cropping. In other instances, more complete underdrainage and special irrigation with cultivation for two or more years has been found necessary.

The experience of R. P. Tjossem, of Ellensburg, Wash., in reclaiming alkali land proves that it can be done by underdrainage and subsequent irrigation. He has tried mole drains and box drains 2 to 2½ feet deep, also box drains 4½ feet deep. His draining was not done systematically but experimentally, and was continued over a field of 72 acres in a random way. He discarded the shallow system of draining early in the work and adopted 4½ feet as the minimum depth at which drains should be placed. He is now of the opinion that 5 feet is preferable. He irrigated liberally, and by subsoiling turned the surface soil down as deeply as possible and irrigated again. The land was seeded as rapidly as possible, the completeness of the reclamation being indicated by the growth of the crops planted. Some parts of the field were soon producing a paying crop, while other portions were more stubborn and required further irrigation and cultivation. At the end

of five years the entire tract produced a profitable crop of alfalfa and timothy. In the sixth year only small spots remained which failed to produce a good average crop of grass. This field at the beginning was badly affected with alkali, and is described as absolutely barren, black alkali being prominent among the salts. The drainage was meager and experimental. The field is now pointed to by neighboring farmers as an example of the successful reclamation of alkali land by underdrainage. The cheapest and most effective methods and the details which practical farmers desire to know are not as fully demonstrated as they will undoubtedly be later on.

Attention was called to this land and the method of its reclamation in Bulletin 49 of the Washington State Experiment Station, issued in 1901, in which is described quite fully the nature of the soil and the percentage of alkali it then contained. The fact that, in 1903, $1,500 worth of hay was harvested and sold from this field, while the land adjoining it remains highly charged with alkali and produces only salt grass, proves in a most positive way the value of drainage as a factor in reclaiming alkali land. A calcareous hardpan is found over a considerable portion of land in that locality. When it is encountered it costs 75 or 80 cents a rod to dig a ditch 5 feet deep by hand labor. Where this does not exist 50 cents a rod is a fair estimate of cost.

The filling of ditches in fields to be irrigated should be done carefully, and every precaution should be taken to make the earth solid over the drains. There will be difficulty in passing irrigation water over a field containing underdrains until the earth over them has become well compacted.